

a distance along the optical axis between those two optical elements, an annular ratio of the secondary light source formed on the exit plane of the fly-eye lens can be changed.

- Further, in the embodiment shown in FIG. 11, design may
 5 be made such that the inner diameter and outer diameter of the aperture stop 6 are variable, and this aperture stop 6 may be disposed at any location which is conjugate with the position at which the secondary light source is formed. For example, it is also conceivable to dispose a stop of which the
 10 diameter of the opening portion is variable on the exit surface side of the fly-eye lens 5, dispose a stop of which the diameter of the light intercepting portion is variable at a location conjugate with the exit surface of the fly-eye lens, and vary the annular ratio and σ value of the annular secondary light source.
 15 In the above described embodiments, the aperture stop may be formed by a transparent type liquid crystal display device, an electrochromic device or the like.

What is claimed is:

1. A projection exposure apparatus including:
 20 illuminating optical means for illuminating a projection negative; and
 projection optical means for projection-exposing said projection negative illuminated by said illuminating optical means onto a substrate;
 25 said illuminating optical means including light source means for supplying exposure light, annular light source forming means for forming an annular secondary light source, which has a plurality of light source images, by the light from said light source means, and condenser means for condensing light from said annular light source forming means on said projection negative;
- 30 said apparatus satisfying the following condition:
 35 $\frac{1}{3} \leq d_1/d_2 \leq \frac{2}{3}$,

where d_1 is the inner diameter of said annular secondary light source, and d_2 is the outer diameter of said annular secondary light source;
 40 said apparatus also satisfying the following condition:

- 45 where NA_1 is the numerical aperture of said projection optical means, and NA_2 is the numerical aperture of said illuminating optical means determined by the outer diameter of said annular secondary light source.

2. A projection exposure apparatus according to claim 1,
 50 wherein said annular light source forming means includes:
 an optical integrator; and
 stop means disposed in the optical path of light emerging from said optical integrator and having an annular opening portion.

- 55 3. A projection exposure apparatus according to claim 2,
 wherein said optical integrator is comprised of a plurality of lens elements.

4. A projection exposure apparatus according to claim 2,
 wherein said optical integrator includes a bar-like optical element.

- 60 5. A projection exposure apparatus according to claim 2,
 wherein said stop means has a plurality of opening portions differing in the ratio of the inner diameter of said annular opening portion to the outer diameter of said annular opening portion from one another, and one of said plurality of opening portions of said stop means is disposed in said optical path.

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6. A projection exposure apparatus according to claim 5, wherein said stop means includes a circular opening portion:

7. A projection exposure apparatus according to claim 5, further including:

driving means for disposing one of said plurality of 5
opening portions in said optical path;

input means for inputting information regarding various
conditions during exposure; and

control means for controlling said driving means on the
basis of the input information from said input means. 10

8. A projection exposure apparatus according to claim 7, wherein said input means includes detecting means for detecting a mark on said projection negative on which the information regarding the various conditions during exposure is recorded. 15

9. A projection exposure apparatus according to claim 1, wherein said projection optical means includes an aperture stop of which the diameter of the opening is variable, and said projection exposure apparatus further includes:

driving means for varying said diameter of the opening of 20
said aperture stop;

input means for inputting information regarding various
conditions during exposure; and

control means for controlling said driving means on the
basis of the input information from said input means. 25

10. A projection exposure apparatus according to claim 1, wherein said annular light source forming means includes light guide means for transmitting said exposure light.

11. A projection exposure apparatus according to claim 10, wherein said light guide means is constructed such that 30
the entrance side cross-sectional shape of said light guide means is circular and the exit side cross-sectional shape of said light guide means is annular.

12. A projection exposure apparatus including:

illumination optical means for illuminating a projection 35
negative; and

projection optical means for projection-exposing said
projection negative illuminated by said illumination
optical means onto a substrate;

said illumination optical means including light source 40
means for supplying exposure light, means for forming
a secondary light source, which has a plurality of light
source images, by the light from said light source
means, means including annular ratio changing means
for converting said secondary light source into an
annular secondary light source and changing a ratio
between an inner diameter and outer diameter of said
annular secondary light source, and condenser means
for condensing light from said annular secondary light
source onto said projection negative, 45

said apparatus satisfying the following condition: 50

$$\frac{d_1}{d_2} \leq \frac{1}{2}$$

where d_1 is the inner diameter of said annular secondary 55
light source, and d_2 is the outer diameter of said annular
secondary light source, and said apparatus satisfying
the following condition:

$$0.45 \leq \frac{NA_2}{NA_1} \leq 0.8$$

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where NA_1 is the numerical aperture of said projection
optical means, and NA_2 is the numerical aperture of
said illumination optical means determined by the outer
diameter of said annular secondary light source.

13. A projection exposure apparatus according to claim 65
12, wherein said means for forming said secondary light
source has an optical integrator.

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14. A projection exposure apparatus according to claim 13, wherein said annular ratio changing means includes stop means disposed in an optical path of light flux emergent from said optical integrator and having an annular opening portion.
- 5 15. A projection exposure apparatus according to claim 14, wherein said stop means includes a plurality of opening portions differing from one another in a ratio of inner diameter of said annular opening portion to outer diameter of said annular opening portion, and one of said plurality of opening portions of said stop means is disposed in the optical path of said illumination optical means.
- 10 16. A projection exposure apparatus according to claim 15, wherein said stop means includes a circular opening portion.
- 15 17. A projection exposure apparatus according to claim 15, further including:
- 20 driving means for disposing one of said plurality of opening portions in said optical path;
- input means for inputting information regarding various conditions during exposure; and
- control means for controlling said driving means on the basis of the input information from said input means.
- 25 18. A projection exposure apparatus according to claim 12, further including:
- input means for inputting information regarding various conditions during exposure; and
- 30 control means for controlling said annular ratio changing means on the basis of the input information from said input means.
- 35 19. A projection exposure apparatus according to claim 18, wherein said annular ratio changing means includes a plurality of opening portions of which a ratio between an inner diameter and an outer diameter is different from one another, and one of said plurality of opening portions is disposed in an optical path of said illumination optical means.
- 40 20. A projection exposure apparatus according to claim 18, wherein said annular ratio changing means is disposed in an optical path of said illumination optical means and includes a movable stop for changing the ratio between the inner diameter and outer diameter.
- 45 21. A projection exposure apparatus comprising: an illuminating optical system; and
- a projection optical system;
- said illumination optical system including a light source, an optical integrator and a condenser optical system;
- 50 light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system, and onto a substrate;
- 55 said optical integrator forming a plurality of annular light source images; and
- the following conditions being satisfied:
- 1/3 ≤ d_1/d_2 ≤ 3/5
- 60 0.45 ≤ NA_2/NA_1 ≤ 0.8
- 65 where d_1 is an inner diameter of said plurality of annular light source images, d_2 is an outer diameter of said plurality of annular light source images, NA_1 is the numerical aperture of said projection optical system at a side of said projection negative and NA_2 is the numerical aperture of said condenser optical system at

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- an exit side determined by the outer diameter of said plurality of annular light source images.
22. A projection exposure apparatus including:
an illumination optical system; and
a projection optical system;
said illumination optical system including a light source,
an optical integrator, an annular stop and a condenser optical system;
light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system and onto a substrate;
- said annular stop being provided at a position where a plurality of images are formed by said illumination optical system;
- said apparatus satisfying the following conditions:

$$\frac{1}{2} \leq d_1/d_2 \leq \frac{3}{2}$$

$$0.45 \leq NA_2/NA_1 \leq 0.8$$

where d_1 is an inner diameter of an opening of said annular stop, d_2 is an outer diameter of the opening of said annular stop, NA_1 is the numerical aperture of said projection optical system at a side of said projection negative and NA_2 is the numerical aperture of said condenser optical system at an exit side determined by the outer diameter of the opening of said annular stop.

23. A projection exposure apparatus comprising:

- an illuminating optical system; and
a projection optical system;
said illuminating optical system including a light source,
an optical integrator, an annular stop and a condenser optical system;
light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system and onto a substrate;
- said illuminating optical system forming a plurality of annular light source images satisfying the following condition:

$$\frac{1}{2} \leq d_1/d_2 \leq \frac{3}{2}$$

where d_1 is an inner diameter of said plurality of annular light source images and d_2 is an outer diameter of said plurality of annular light source images; and

said projection exposure apparatus satisfying the following condition:

$$0.45 \leq NA_2/NA_1 \leq 0.8,$$

where NA_1 is the numerical aperture of said projection optical system at a side of said projection negative, and NA_2 is the numerical aperture of said condenser optical system at an exit side determined by an outer diameter of an opening of said annular stop.

24. A projection exposure apparatus comprising:

- an illuminating optical system; and
a projection optical system;

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said illuminating optical system including a light source,
an optical integrator and a condenser optical system;
light from said light source passing through said optical
integrator, said condenser optical system, a projection
negative and said projection optical system and onto a
substrate;

5 said illuminating optical system forming a plurality of
annular light source images satisfying the following
condition:

10 $\frac{1}{3} \leq d_1/d_2 \leq \frac{2}{3}$,

where d_1 is an inner diameter of said plurality of annular
light source images, d_2 is an outer diameter of said
plurality of annular light source images;

15 the ratio between the inner diameter and the outer diameter
of said annular light source images being variable
within the range of said condition;

20 said projection exposure apparatus satisfying the follow-
ing condition:

25 $0.45 \leq NA_2/NA_1 \leq 0.8$,

where NA_1 is the numerical aperture of said projection
optical system at a side of said projection negative, and
25 NA_2 is the numerical aperture of said condenser optical
system at an exit side determined by the outer diameter
of said plurality of annular light source images.

25. A projection exposure apparatus comprising:

30 an illuminating optical system; and

a projection optical system;

35 said illuminating optical system including a light source,
an optical integrator, a first annular stop, a second
annular stop and a condenser optical system;

light from said light source passing through said optical
integrator, said condenser optical system, a projection
negative and said projection optical system and onto a
substrate;

40 said first and second annular stops satisfying the follow-
ing condition:

45 $\frac{1}{3} \leq d_1/d_2 \leq \frac{2}{3}$,

where d_1 is an inner diameter of an opening of said
annular stops and d_2 is an outer diameter of an opening
of said annular stops;

50 said first and second annular stops being selectively
disposed in a position where a plurality of light source
images are formed by said illuminating optical system;
and

55 said projection exposure apparatus satisfying the follow-
ing condition:

60 $0.45 \leq NA_2/NA_1 \leq 0.8$,

55 where NA_1 is the numerical aperture of said projection
optical system at a side of said projection negative, and
 NA_2 is the numerical aperture of said condenser optical
system at an exit side determined by the outer diameter
of said plurality of annular light source images.

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1 26. A projection exposure apparatus comprising:
2 an illumination optical system including an optical
3 integrator that forms a substantially annular secondary
4 light source; and

5 a projection optical system,
6 said illumination optical system satisfying the
7 following condition:

8
$$1/3 \leq d_1/d_2 \leq 2/3$$

9 wherein d_1 is an inner diameter of the secondary light
10 source and d_2 is an outer diameter of the secondary light
11 source.

1 27. A projection exposure apparatus comprising:
2 an illumination optical system including an optical
3 integrator through which a light beam irradiated on a mask
4 passes; and

5 a projection optical system;
6 said illumination optical system providing an intensity
7 distribution of the light beam with an annular increased
8 intensity portion relative to the inside thereof, and
9 said illumination optical system satisfying the
10 following condition:

11
$$0.45 \leq NA_2/NA_1 \leq 0.8$$

12 wherein NA_1 is the numerical aperture of said
13 projection optical system, and NA_2 is the numerical aperture
14 of light from the increased intensity portion.

1 28. A projection exposure apparatus comprising:
2 an illumination optical system including an optical
3 integrator through which a light beam irradiated on a mask
4 passes; and
5 a projection optical system;
6 said illumination optical system providing an intensity
7 distribution of the light beam with an annular increased
8 intensity portion relative to the inside thereof and
9 changing the intensity distribution in accordance with a
10 pattern formed on the mask so as to maintain a shape of the
11 annular increased intensity portion.

1 29. A projection exposure apparatus comprising:
2 an illumination optical system disposed between a light
3 source and a mask;
4 a projection optical system disposed between the mask
5 and a substrate; and
6 an optical device, disposed within the illumination
7 optical system, that forms a plurality of secondary light
8 sources including a substantially annular secondary light
9 source and a substantially circular secondary light source
10 with light from the light source to illuminate the mask with
11 light from one of the plurality of secondary light sources,
12 the optical device changing an intensity distribution of the
13 annular secondary light source so as not to change the shape
14 thereof and changing an intensity distribution of the

~~15 circular secondary light source so as not to change the~~
~~16 shape thereof.~~

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1 30. A combination of an illuminator and a
2 photolithographic projection imager, the combination
3 comprising:
4 a. an illuminator optical system for directing
5 illumination from a source to a pupil of the illuminator
6 from which a reticle is illuminated to be imaged on a wafer
7 by an objective imaging system;
8 b. the illuminator in a collimated region of
9 illumination upstream of the illuminator pupil having a pair
10 of refractive elements having conical surfaces that are
11 respectively concave and convex;
12 c. said elements being arranged so that an upstream
13 one of said elements diverges the illumination into a single
14 beam having an annular configuration of intensity and a
15 downstream one of said elements counters the divergence
16 caused by the upstream element to give the illumination an
17 annular intensity profile of the single beam at the pupil of
18 the illuminator; and
19 d. a uniformizer arranged between said elements and
20 the pupil of the illuminator.

1 31. The combination of Claim 30, wherein the distance
2 between said elements is variable to vary the radius of said
3 annular intensity profile.

1 32. The combination of Claim 31, wherein said distance
2 between said elements can be reduced enough to counter said

3 divergence approximately at its source to keep said
4 intensity configuration from becoming annular.

1 33. The combination of Claim 30, wherein said upstream
2 element has said concave conical surface and said downstream
3 element has said convex conical surface.

1 34. The combination of Claim 30, wherein a mask is
2 positionable at said pupil within said annular intensity
3 profile.

1 35. The combination of Claim 30, wherein said concave
2 and convex conical surfaces have the same conic angle.

1 36. The combination of Claim 30, wherein said elements
2 are separated by an air gap.

1 37. The combination of Claim 30, wherein said conical
2 surfaces are arranged to confront each other.

1 38. The combination of Claim 37, wherein the distance
2 between said elements is variable to vary the radius of said
3 annular intensity profile to accommodate characteristics of
4 the reticle.

1 39. The combination of Claim 38, wherein said conical
2 surfaces can be moved into proximity for countering said

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3 divergence to keep said intensity configuration from
4 becoming annular.

1 40. The combination of Claim 39, wherein a mask of
2 variable size is positionable downstream of said conical
3 surfaces within said annular intensity profile.

1 41. The combination of Claim 30, wherein said
2 refractive elements are faceted.

1 42. In an illuminator for a photolithographic
2 projection imager, the improvement comprising:

3 a. a first refractive element arranged in a collimated
4 region of an illumination path of said illuminator upstream
5 of a pupil of said illuminator so that a conical surface of
6 said first refractive element diverges the illumination into
7 a single beam having an annular configuration of intensity;

8 b. a second refractive element arranged to receive
9 diverged illumination from said first refractive element and
10 said second refractive element having a conical surface
11 arranged for countering the illumination divergence caused
12 by said first refractive element to fix the radius of the
13 divergence of the single beam of said illumination;

14 c. the radius of divergence of the illumination output
15 from the second refractive element appearing as an annular
16 intensity profile of illumination at the pupil region of the
17 illuminator causing illumination with an annular intensity

18 profile to illuminate a reticle that is imaged onto a wafer
19 by an objective imaging system of the photolithographic
20 projection imager; and
21 d. a uniformizer arranged between said first and
22 second refractive elements and the pupil of the illuminator.

1 43. The improvement of Claim 42, wherein said conical
2 surface of said first refractive element is concave, and
3 said conical surface of said second refractive element is
4 convex.

1 44. The improvement of Claim 42, wherein said first
2 and second refractive elements are separated by an air gap.

1 45. The improvement of Claim 42, wherein a distance
2 between said refractive elements is variable for varying
3 said radius of illumination divergence to accommodate
4 characteristics of the reticle.

1 46. The improvement of Claim 45, wherein a minimum of
2 said variable distance between said refractive elements
3 results in said second element countering the illumination
4 divergence so that the configuration of illumination
5 intensity does not become annular.

1 47. The improvement of Claim 45, including a variable
2 size mask arranged for blocking illumination within said
3 annular configuration of intensity.

1 48. The improvement of Claim 42, wherein said conic
2 surfaces of said first and second refractive elements have
3 the same conic angle.

1 49. The improvement of Claim 42, wherein said conic
2 surface of said first and second refractive elements
3 confront each other.

1 50. The improvement of Claim 49, wherein a distance
2 between said refractive element is variable for varying said
3 radius of illumination divergence to accommodate
4 characteristics of the reticle.

1 51. The improvement of Claim 50, wherein said
2 illumination divergence is substantially eliminated by
3 moving said conic surfaces into proximity.

1 52. The improvement of Claim 50, wherein illumination
2 within said annular configuration of intensity is blocked by
3 a mask.

1 53. The improvement of Claim 42, wherein said conic
2 surfaces of said first and second refractive elements face
3 away from each other.

1 54. The improvement of Claim 42, wherein said
2 refractive elements are faceted.

1 55. An illuminator combined with a photolithographic
2 projection imager, the combination comprising:

3 a. the illuminator having an optical system for
4 directing illumination along an optical axis of the
5 illuminator upstream of a pupil of the illuminator so that
6 an intensity profile of the illumination as the illuminator
7 pupil is directed to a reticle that is imaged on a wafer by
8 an objective imaging system of the photolithographic
9 projection imager;

10 b. a diverging element arranged in a collimated region
11 of the illumination path of said illuminator upstream of the
12 illuminator pupil for diverging said illumination into a
13 single beam having an annular configuration of intensity;

14 c. a counter diverging element arranged in said
15 illumination path at a variable distance from said diverging
16 element for receiving said diverging illumination;

17 d. said counter diverging element being arranged for
18 countering the divergence of said illumination and fixing
19 the radius of said annular configuration of intensity of the

20 single beam as a function of the distance between said
21 elements;
22 e. the annular configuration of illumination intensity
23 output from the counter diverging element appearing as an
24 annular intensity profile of the single beam of the
25 illumination at the illuminator pupil and at the reticle so
26 that the radius of the annular intensity profile
27 accommodates characteristics of the reticle; and
28 f. a uniformizer arranged between said elements and
29 the pupil of the illuminator.

1 56. The combination of Claim 55, wherein said elements
2 are refractive and have faceted surfaces.

1 57. The combination of Claim 55, wherein said elements
2 are concentrically diffractive.

1 58. The combination of Claim 55, wherein said elements
2 are reflective and have conical surfaces.

1 59. The combination of Claim 55, wherein said elements
2 are refractive and have conical surfaces.

1 60. The combination of Claim 59, wherein said conical
2 surfaces are concave on one of said elements and convex on
3 another of said elements.

1 61. The combination of Claim 60, wherein said concave
2 and convex conical surfaces confront each other.

1 62. The combination of Claim 61, wherein said counter
2 diverging element can be positioned for countering said
3 diverging illumination so that the illumination intensity
4 profile does not become annular.

1 63. The combination of Claim 60, wherein said concave
2 and convex conical surfaces face away from each other.

1 64. The combination of Claim 55, wherein said
2 diverging element is refractive and has a concave conical
3 surface.

1 65. The combination of Claim 55, wherein said counter
2 diverging element is refractive and has a convex conical
3 surface.

1 66. The combination of Claim 55, wherein said counter
2 diverging element can be positioned for countering said
3 diverging illumination so that said intensity configuration
4 does not become annular.

1 67. The combination of Claim 55, including a variable
2 size mask positioned to block illumination within said
3 annular configuration.

1 --68. An illuminator for a photolithographic
2 projection imager including a variable annular illumination
3 intensity profiler, said profiler comprising a pair of
4 diverging and counter diverging elements arranged in the
5 illumination path of said illuminator so that said diverging
6 element diverges the illumination into an annular
7 configuration of intensity and said counter diverging
8 element counters the divergence caused by said diverging
9 element to give the illumination an annular intensity
10 profile the configuration of which is a function of the
11 distance between the pair of elements.--

1 --69. An illuminator according to Claim 68, wherein
2 the diverging element is a refractive element having a
3 concave conical surface and the counter diverging element is
4 a refractive element having a convex conical surface.--

1 --70. An illuminator according to Claim 68, wherein
2 the diverging and counter diverging elements are refractive
3 elements that are faceted.--

1 --71. An illuminator according to Claim 68, wherein
2 said diverging and counter diverging elements are
3 concentrically diffractive.--

1 --72. An illuminator according to Claim 68, wherein
2 the diverging and counter diverging elements are reflective
3 and have conical surfaces.--

1 --73. An illuminator according to Claim 68, wherein
2 the diverging element is a first refractive element arranged
3 in the illumination path of the illumination upstream of a
4 pupil region of said illuminator so that a conical surface
5 of said first refractive element diverges the illumination
6 into an annular configuration of intensity, and said counter
7 diverging element is a second refractive element arranged to
8 receive diverged illumination from said first refractive
9 element, said second refractive element having a conical
10 surface arrangeable for countering the illumination
11 divergence caused by said first refractive element and
12 fixing the radius of the divergence of said illumination.--

1 --74. An illuminator according to any of Claims 68 to
2 73, wherein the distance between the diverging and counter
3 diverging elements is variable to vary the radius of the
4 annular intensity profile.--

1 --75. An illuminator according to any of Claims 68 to
2 73, wherein the distance between the diverging and counter
3 diverging elements can be reduced enough to counter said
4 divergence approximately at its source to keep the intensity
5 configuration from becoming annular.--

1 --76. An illuminator according to any of Claims 68-73,
2 wherein the diverging and counter diverging elements are
3 arranged on the optical axis of the illuminator upstream of
4 a pupil region of said illuminator.--

1 --77. An illuminator according to Claim 76, wherein a
2 mask is positioned at the pupil region within the annular
3 intensity profile.--

1 --78. An illuminator according to any of Claims 68 to
2 73, wherein the diverging and counter diverging elements are
3 separated by an air gap.--

1 --79. An illuminator according to Claim 69 or 73,
2 wherein the concave and convex conical surfaces have the
3 same conic angle.--

1 --80. An illuminator according to Claim 69 or 73,
2 wherein the conical surfaces are arranged to confront each
3 other.--

1 --81. An illuminator according to Claim 69 or 73,
2 wherein the conical surfaces can be moved into proximity for
3 countering the divergence to keep the intensity
4 configuration from becoming annular.--

--82. An illuminator according to Claim 69 or 73,
wherein a mask of variable size is positioned downstream of
said conical surfaces within said annular intensity
profile.--

--83. An illuminator according to Claim 73, wherein
the conical surface of the first refractive element is
concave, and the conical surface of the second refractive
element is convex.--

--84. An illuminator according to any of Claims 68-73
or 83, wherein a variable size mask is arranged within the
illumination path for blocking illumination within the
annular configuration of intensity.--

~~1 --85. An illuminator according to Claim 84, wherein~~
~~2 said illumination divergence is substantially eliminated by~~
~~3 moving said conic surfaces into proximity.--~~

1 --86. An illuminator according to any of Claims 68-73,
2 wherein the illumination within said annular configuration
3 of intensity is blocked by a mask.--

1 --87. An illuminator according to Claim 69 or 73,
2 wherein the conic surfaces of the refractive elements face
3 away from each other.--

1 --88. An illuminator according to Claim 73, wherein
2 the refractive elements are faceted.--

1 --89. An illuminator according to Claim 79, wherein
2 the concave and convex conical surfaces face away from each
3 other.--

1 --90. An illuminator according to Claim 68 or 69,
2 wherein a variable size mask is positioned within said
3 illuminator to block illumination within said annular
4 configuration.--

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